

What is claimed is:

1. A method, comprising:

identifying a set of virtual private network (VPN) customers, at least one mobile access point (MAP) and at least one customer premise equipment (CPE) associated with each VPN customer, and at least one IP service gateway (IPSG) for facilitating VPN tunneling between a MAP and a CPE, wherein each MAP is geographically remote from each IPSG; and

selecting a subset of IPSGs to maximize total profit resulting from provisioning a subset of VPN customers on the selected IPSGs, wherein said total profit from all the customers comprises the sum of profits from each customer ( $I$ ), where for each customer profit ( $U^I$ ) equals weighted revenue ( $\gamma V^I$ ) less cost ( $C^I$ ), ( $U^I = \gamma V^I - C^I$ ), wherein said cost per customer comprises a total tunnel bandwidth cost ( $C_C^I$ ) from said MAP to said CPE, and a cost ( $C_V^I$ ) of provisioning an IPSG node.

2. The method of claim 1, wherein  $\gamma$  represents relative weight of revenue compared to total cost for customer  $I$ .

3. The method of claim 1, wherein said total tunnel bandwidth cost comprises a dynamic tunnel bandwidth cost between said MAP and said provisioned IPSG, and a static tunnel bandwidth cost between said provisioned IPSG and said CPE.

4. The method of claim 1, wherein only a single tunnel is established between said provisioned IPSG and said CPE, even during instances where traffic from multiple MAPs are going through said provisioned IPSG to reach said CPE.

5. The method of claim 1, wherein in an instance said provisioned IPSG sends traffic to more than one CPE, said provision cost is counted only once.

6. The method of claim 1, wherein said cost per customer  $l$  is determined by

$$C^l = \left( \sum_{i \in P, j \in Q} c'_{ij} + \beta \sum_{j \in Q, k \in R_l} d'_{jk} \right) + \alpha \sum_{j \in Q} f_j y'_j, \text{ where } c'_{ij} \text{ is a bandwidth cost associated}$$

with sending traffic from a MAP node  $i$  to an IPSG node  $j$ ,  $d'_{jk}$  is a bandwidth cost associated with sending traffic from said IPSG node  $j$  to said CPE node  $k$ ,  $\beta$

5 represents a weighing factor with respect to said shared static tunnel,  $f_j$  is a provisioning cost associated with using said IPSG node  $j$ ,  $y'_j$  is a binary variable denoting whether said IPSG  $j$  is provisioned for a provisioned customer to send traffic to at least one of its CPEs, and  $\alpha$  is a weighing factor for provision cost over total bandwidth cost.

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7. The method of claim 6, wherein said bandwidth cost ( $c'_{ij}$ ) associated with sending traffic from a MAP node  $i$  to an IPSG node  $j$  comprises the product of unit bandwidth cost ( $a_{ij}$ ) between said MAP node  $i$  and said IPSG node  $j$ , and a sum of

traffic  $\left( \sum_{k \in R_l} s'_{ijk}, \forall i \in P, \forall j \in Q \right)$  from MAP node  $i$  to said CPE node  $k$  that is directed

15 through IPSG node  $j$ .

8. The method of claim 6, wherein said bandwidth cost ( $d'_{jk}$ ) associated with sending traffic from an IPSG node  $j$  to a CPE node  $k$  comprises the product of unit bandwidth cost ( $e'_{jk}$ ) between said IPSG node  $j$  and said CPE node  $k$ , and a total

20 amount of traffic  $\left( \sum_{i \in P} s'_{ijk}, \forall j \in Q, \forall k \in R_l \right)$  from MAP node  $i$  to said CPE node  $k$  that is directed through IPSG node  $j$ .

9. The method of claim 6, wherein said total amount of traffic  $\left( \sum_{k \in R_l} s'_{ijk} \right)$  from

MAP node  $i$  to said IPSG node  $j$  is less than or equal to total bandwidth capacity

25 ( $g_{ij}$ ) between said MAP node  $i$  and said IPSG node  $j$ .

10. The method of claim 6, wherein said total amount of traffic  $\left(\sum_{i \in P} s'_{ijk}\right)$  from said IPSP node  $j$  to said CPE node  $k$  is less than or equal to total bandwidth capacity ( $h'_{jk}$ ) between said IPSP node  $j$  and said CPE node  $k$ .
- 5 11. A virtual private network (VPN) system architecture, comprising:  
means for identifying a set of virtual private network (VPN) customers, at least one mobile access point (MAP) and at least one customer premise equipment (CPE) associated with each VPN customer, and at least one IP service gateway (IPSG) for facilitating VPN tunneling between a MAP and a CPE, wherein each  
10 MAP is geographically remote from each IPSG; and  
means for selecting a subset of IPSGs to maximize total profit resulting from provisioning a subset of VPN customers on the selected IPSGs, wherein said total profit from all the customers comprises the sum of profits from each customer ( $l$ ), where for each customer profit ( $U^l$ ) equals weighted revenue ( $\gamma V^l$ ) less cost ( $C^l$ ),  
15 ( $U^l = \gamma V^l - C^l$ ), wherein said cost per customer comprises a total tunnel bandwidth cost ( $C^l_c$ ) from said MAP to said CPE, and a cost ( $C^l_v$ ) of provisioning an IPSG node.  
  
12. The method of claim 11, wherein  $\gamma$  represents relative weight of revenue  
20 compared to total cost for customer  $l$ .  
  
13. The method of claim 11, wherein said total tunnel bandwidth cost comprises a dynamic tunnel bandwidth cost between said MAP and said provisioned IPSG, and a static tunnel bandwidth cost between said provisioned IPSG and said CPE.  
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14. The method of claim 11, wherein only a single tunnel is established between said provisioned IPSG and said CPE, even during instances where traffic from multiple MAPs are going through said provisioned IPSG to reach said CPE.

15. The method of claim 11, wherein in an instance said provisioned IPSG sends traffic to more than one CPE, said provision cost is counted only once.

16. The method of claim 11, wherein said cost per customer  $l$  is determined by

$$5 \quad C^l = \left( \sum_{i \in P, j \in Q} c'_{ij} + \beta \sum_{j \in Q, k \in R_l} d'_{jk} \right) + \alpha \sum_{j \in Q} f_j y'_j, \text{ where } c'_{ij} \text{ is a bandwidth cost associated}$$

with sending traffic from a MAP node  $i$  to an IPSG node  $j$ ,  $d'_{jk}$  is a bandwidth cost associated with sending traffic from said IPSG node  $j$  to said CPE node  $k$ ,  $\beta$

represents a weighing factor with respect to said shared static tunnel,  $f_j$  is a provisioning cost associated with using said IPSG node,  $y'_j$  is a binary variable

10 denoting whether said IPSG  $j$  is provisioned for a provisioned customer to send traffic to at least one of its CPEs, and  $\alpha$  is a weighing factor for provision cost over total bandwidth cost.

17. The method of claim 16, wherein said bandwidth cost ( $c'_{ij}$ ) associated with

15 sending traffic from a MAP node  $i$  to an IPSG node  $j$  comprises the product of unit bandwidth cost ( $a_{ij}$ ) between said MAP node  $i$  and said IPSG node  $j$ , and a sum of

traffic  $\left( \sum_{k \in R_l} s'_{ijk}, \forall i \in P, \forall j \in Q \right)$  from MAP node  $i$  to said CPE node  $k$  that is directed

through IPSG node  $j$ .

20 18. The method of claim 16, wherein said bandwidth cost ( $d'_{jk}$ ) associated with

sending traffic from an IPSG node  $j$  to a CPE node  $k$  comprises the product of unit bandwidth cost ( $e'_{jk}$ ) between said IPSG node  $j$  and said CPE node  $k$ , and a total

amount of traffic  $\left( \sum_{i \in P} s'_{ijk}, \forall j \in Q, \forall k \in R_l \right)$  from MAP node  $i$  to said CPE node  $k$  that

is directed through IPSG node  $j$ .

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19. The method of claim 16, wherein said total amount of traffic  $\left( \sum_{k \in R_i} s'_{ijk} \right)$  from MAP node  $i$  to said IPSP node  $j$  is less than or equal to total bandwidth capacity  $(g_{ij})$  between said MAP node  $i$  to said IPSP node  $j$ .
- 5 20. The method of claim 16, wherein said total amount of traffic  $\left( \sum_{k \in P} s'_{ijk} \right)$  from said IPSP node  $j$  to said CPE node  $k$  is less than or equal to total bandwidth capacity  $(h'_{jk})$  between said IPSP node  $j$  and said CPE node  $k$ .
21. The system architecture of claim 11, wherein said MAPs provide dynamic  
10 switching and routing of data connections, while said IPSPs provide VPN services.
22. A computer readable medium for storing instructions that, when executed by a processor, perform a method for optimally provisioning connectivity for network-based mobile virtual private network (VPN) services, comprising  
15 identifying a set of virtual private network (VPN) customers, at least one mobile access point (MAP) and at least one customer premise equipment (CPE) associated with each VPN customer, and at least one IP service gateway (IPSP) for facilitating VPN tunneling between a MAP and a CPE, wherein each said MAP is geographically remote from each said IPSP; and  
20 selecting a subset of IPSPs to maximize total profit resulting from provisioning a subset of VPN customers on the selected IPSPs, wherein said total profit from all the customers comprises the sum of profits from each customer  $(I)$ , where for each customer profit  $(U')$  equals weighted revenue  $(\gamma V')$  less cost  $(C')$   $(U' = \gamma V' - C')$ , wherein said cost per customer comprises a total tunnel bandwidth cost  $(C'_C)$  from  
25 said MAP to said CPE, and a cost  $(C'_V)$  of provisioning an IPSP node.